



# NICER: Neutron Star Interior Composition ExploreR and SEXTANT

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## SEXTANT

# NICER Mission Overview

*Astrophysics on the International Space Station:  
Understanding ultra-dense matter through soft X-ray timing*

- **Science:** A proposed International Space Station (ISS) payload dedicated to the study of **neutron stars**—a fundamental investigation of extremes in gravity, material density, and electromagnetic fields.
- **Spacecraft:** Hosted on the ISS Express Logistics Carrier
- **Launch:** CBE= August 2016 by JAXA HIIIB/HTV or Space-X Falcon 9/Dragon
- **Duration:** 18 (min.12) months
- **Team:** NASA GSFC, MIT. Science co-Is from USRA, UMCP, UMBC, NRL, University of Arizona, McGill, SUNY, MSU, F&M, NRAO, UNAM.



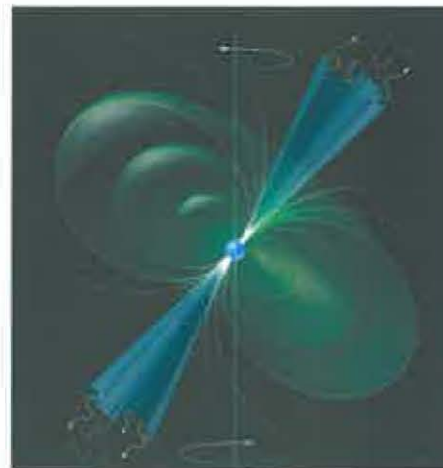
# NICER: The Science Argument



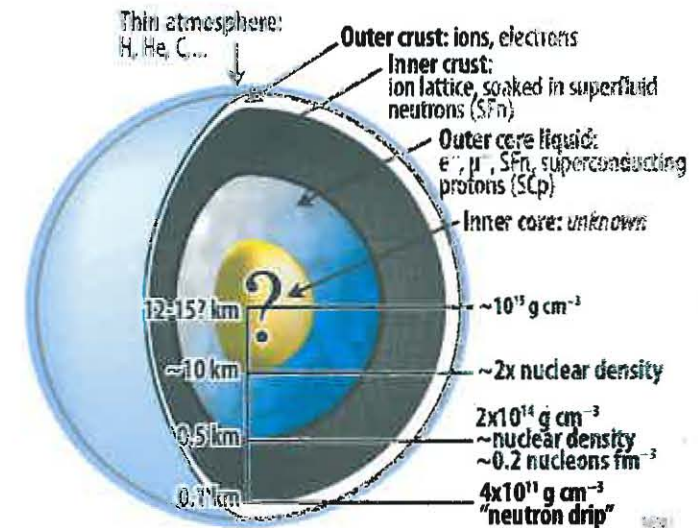
# NICER Science Objectives

*Neutron stars—Unique environments in which all four fundamental forces of Nature are simultaneously important.*

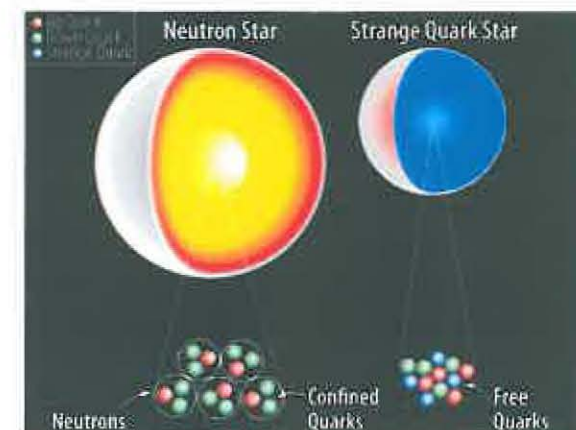
- To address NASA and National Academy of Sciences **strategic questions**
- To resolve the nature of **ultradense matter** at the threshold of collapse to a black hole
- To reveal **interior composition, dynamic processes, and radiation mechanisms** of neutron stars.



Credit: M. Garlick



Objective	Measurements
<b>Structure</b> —Reveal the nature of matter in the interiors of neutron stars.	Neutron star radii to $\pm 5\%$ . Cooling timescales.
<b>Dynamics</b> —Uncover the physics responsible for the dynamic behavior of neutron stars.	Stability of pulsars as clocks. Properties of outbursts, oscillations, and precession.
<b>Energetics</b> —Determine how energy is extracted from neutron stars.	Intrinsic radiation patterns, spectra, and luminosities.

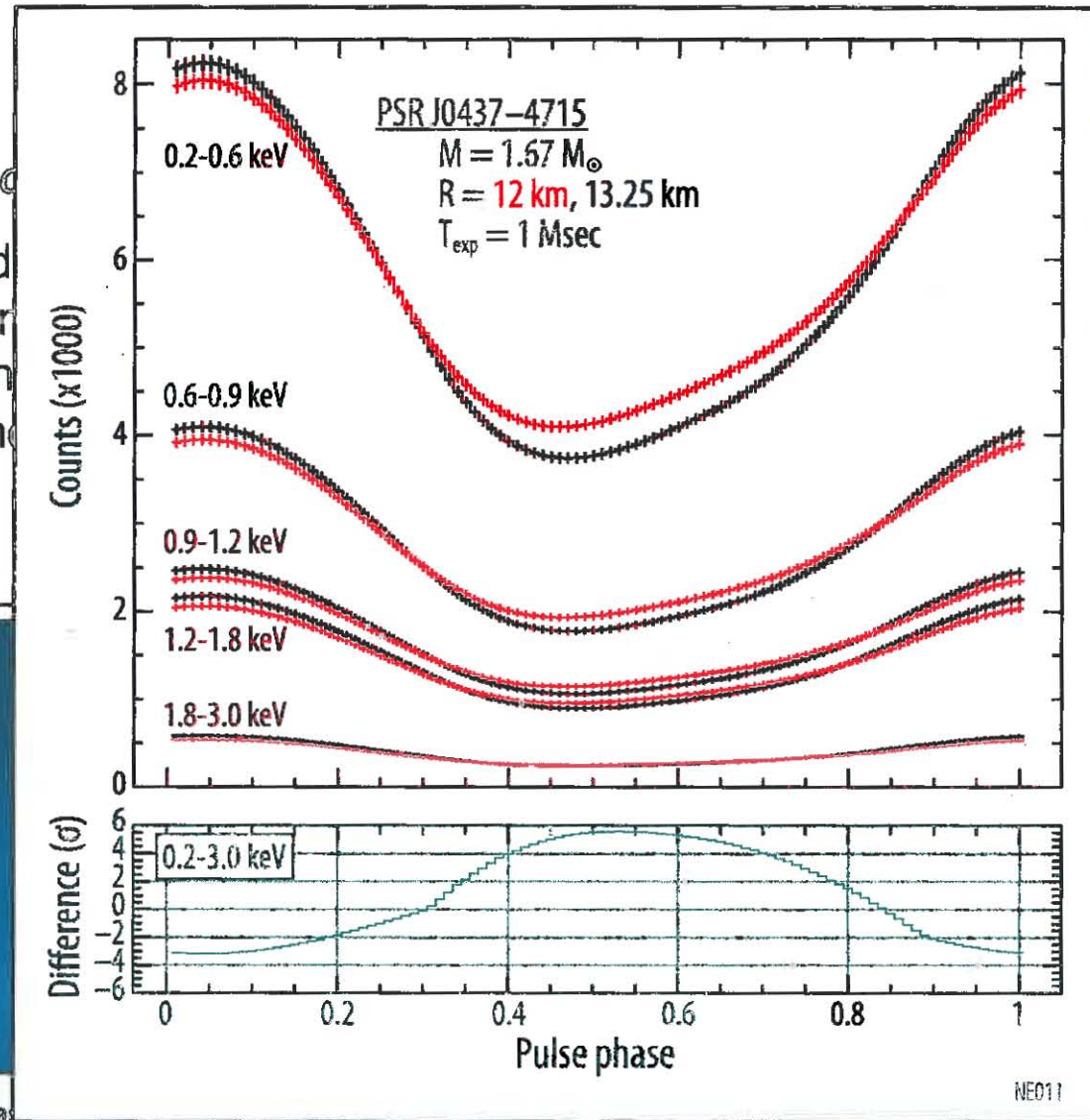
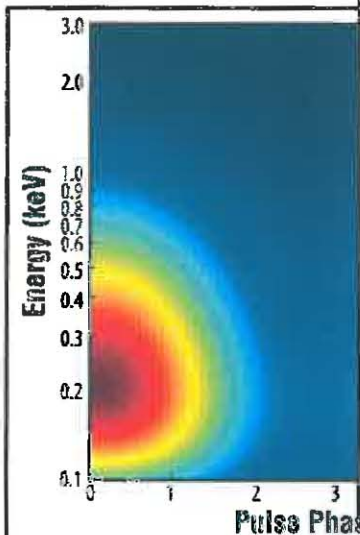


# NICER Science Measurements

*Structure through lightcurve modeling, long-term timing, and pulsation searches*

## Lightcurve modeling

Shape of model  
constrains compactness ( $M/R$ ) and  
viewing geometry



promises

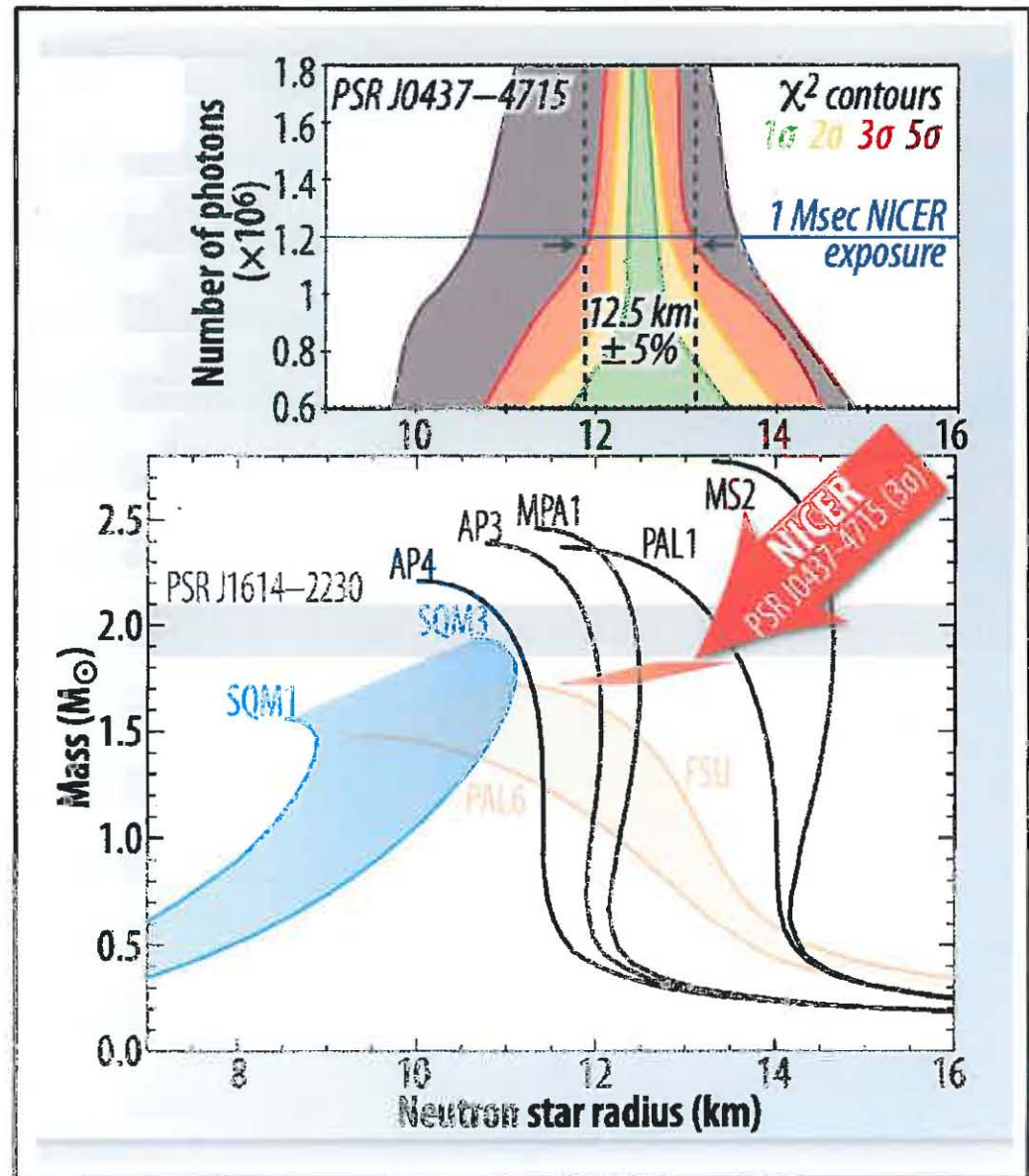


# NICER Science Measurements

*Structure through lightcurve modeling, long-term timing, and pulsation searches*

Simulations demonstrate how well an assumed neutron star radius can be recovered.

The resulting allowed regions in the  $M$ - $R$  plane rule out proposed families of neutron star equations of state. The best mass measurements alone can't distinguish among competing models.

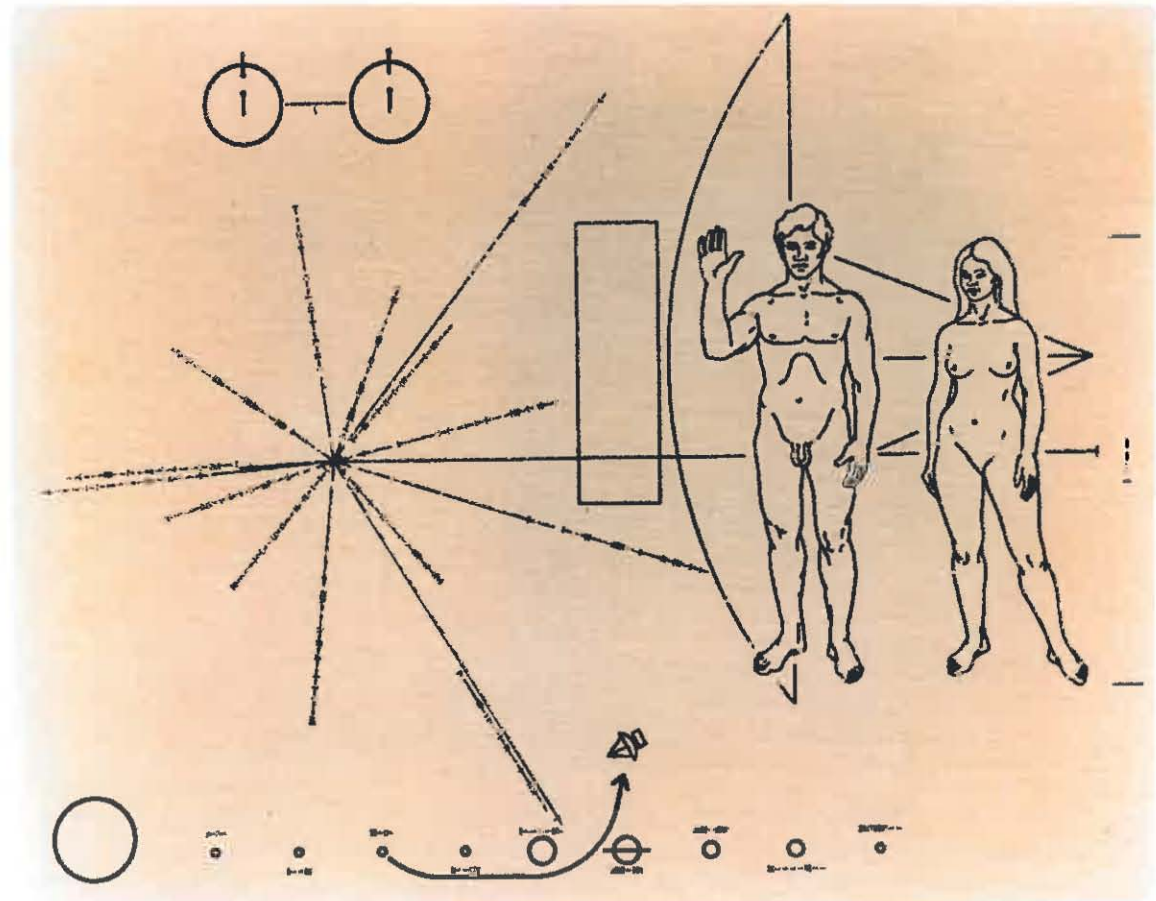


# The Technology Demonstration Argument: XNAV and Pulsar Based Navigation

Pulsars were discovered in 1967 and immediately were recognized as a tool for Galactic navigation.

A map showing where the Solar system is relative to the known pulsars at the time.

Pioneer Plaque: Flown on the Pioneer 10 Spacecraft

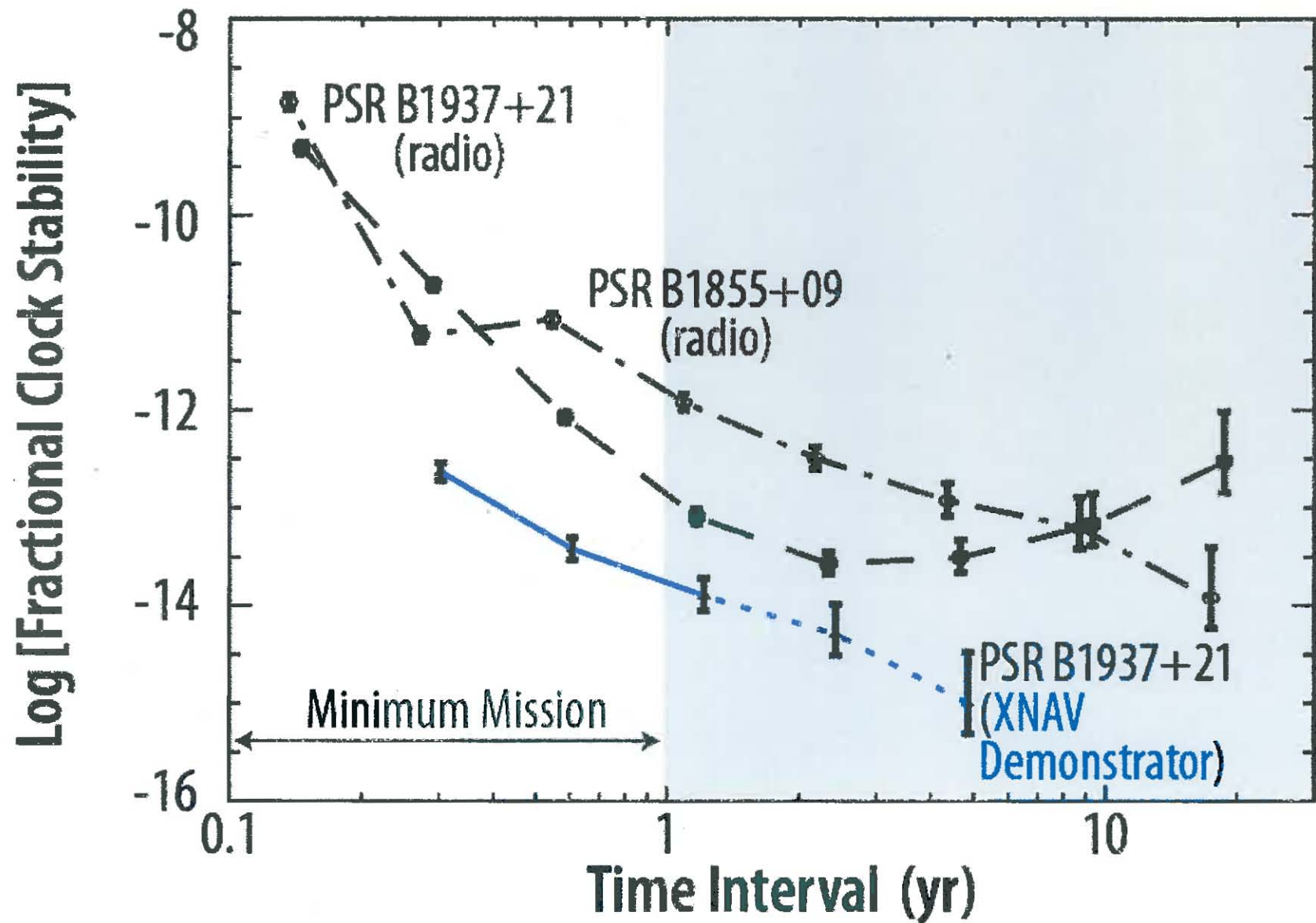


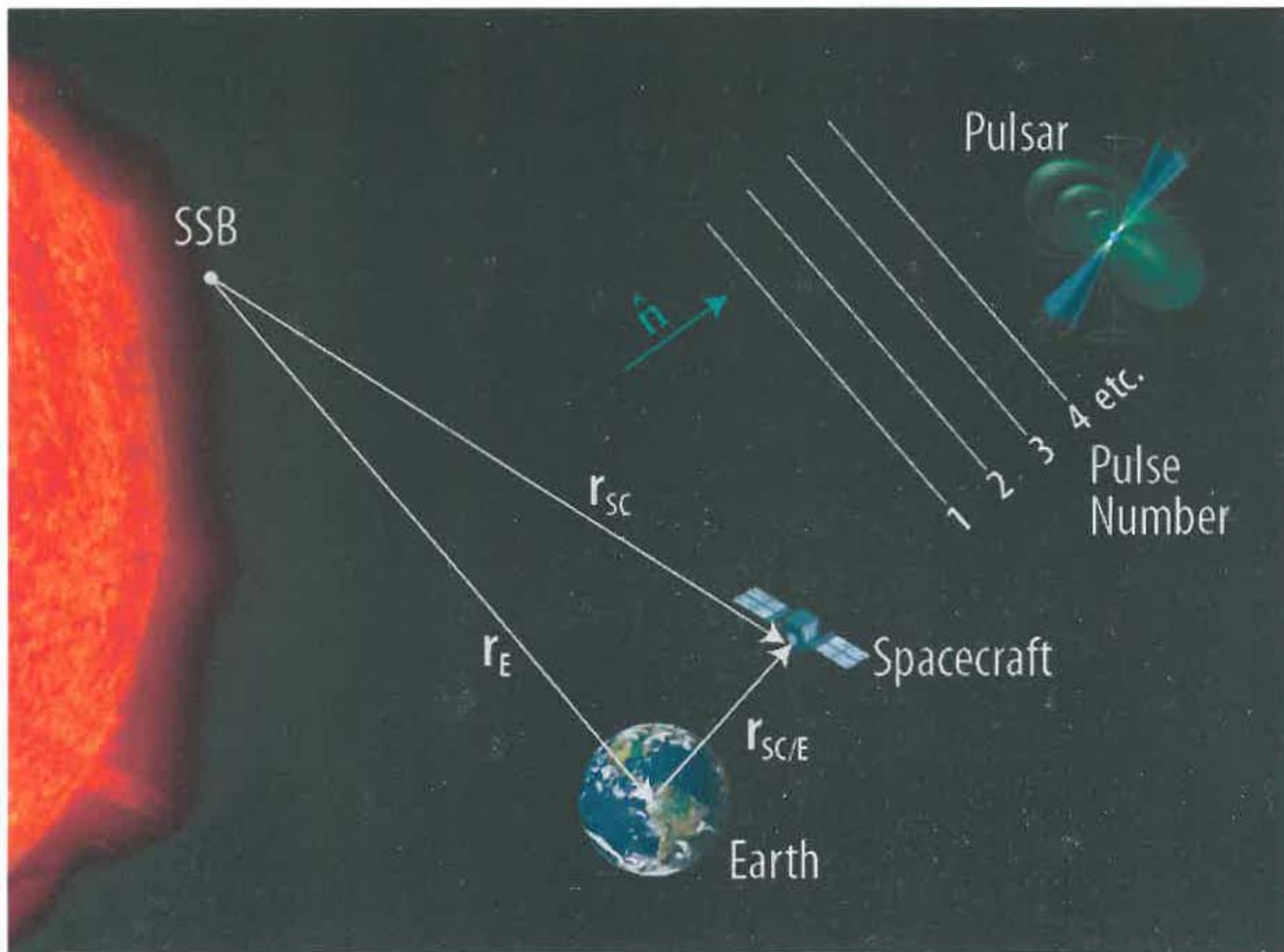


# Clocks and Navigation

- You find atomic clocks on GPS satellites that provide the infrastructure for a navigation solution that works on the Earth and nearby...
- Pulsars are distributed on a Galactic scale providing a natural infrastructure for a GPS-like navigation solution that works throughout the Solar system and beyond.

**Pulsars are very stable clocks that are comparable or better than atomic clocks on long time scales**









[illegible]

# Expected Accuracy

- Dependent on orbit
  - How fast things change
  - Integration time on pulsars
- $< 500$  m for LEO orbit in a day
  - Timescale for updates 1000s of seconds
- $< 100$ m for interplanetary in a few days



# XNAV compared to other deep space navigation tools

**Table 1:** With typical position determinations to 500 m in one day or less virtually anywhere in the Solar System, XNAV provides unprecedented, mission-enabling navigation solutions across a wide range of space applications. (L/A: Limited Applicability, N/A: Not Applicable)

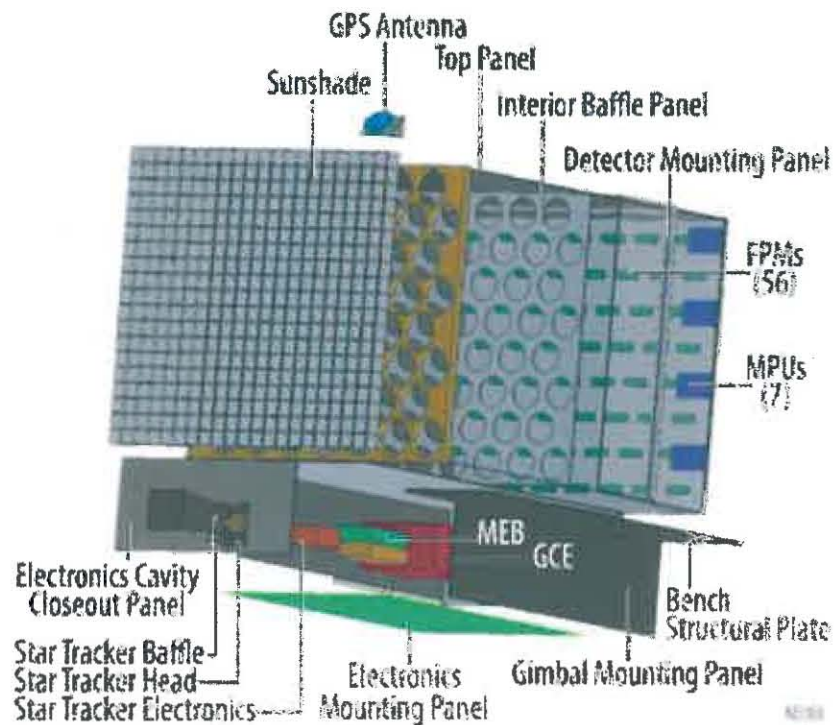
NASA Mission Orbit	GPS	TDRSS	NEN / DSN	ΔDOR (DSN)	CELNAV/Optical	Requirement/Source
LEO	30 cm @ 1 Hz, 2 cm @ 1 day	2–8 m @ 1 orbit	2–8 m @ 1 orbit	L/A	1 km @ 1 hr	≤ few m
HEO (perigee < 2R <sub>Earth</sub> )	10 m @ 1 Hz, 1 m @ 1 day	100 m	100 m	L/A	0.1–15 km @ 1 orbit	< 1 km/many
GEO	3 m @ 1 Hz, 50 cm @ 1 day	N/A	1–8 m @ 4–8 hrs	L/A	1–5 km @ 1 orbit	10s of m/many
Lunar, in view	L/A	N/A	200 m @ 2 days	L/A	0.5 km @ 0.5 days	500 m/LRO
Lunar, far side/bi-lat	N/A	N/A	N/A	N/A	0.5 km @ 0.5 days	500 m/LRO
Sun-Earth L1/L2	N/A	N/A	2 km @ 3 weeks	L/A	5–20 km @ 3 days	2 km/WMAP
Mars (front side)	N/A	N/A	10s of km	1 km @ 1 day, meters @ days	10s of km (front or back)	~5 km/orbit insert, 5–10 m/science @ days
Jupiter	N/A	N/A	10s of km	Few km	10s of km	~1–5 km/insert
Beyond Jupiter	N/A	N/A	100s of km	100 km	10s of km	~1–5 km/insert

XNAV provides more utility compared to existing navigation methods as we venture further away from Earth.

At the greatest distances, the “Deep Space Network” (DSN) provide excellent distance information from the earth, but MUCH less information in the cross-direction.

# The Instrument

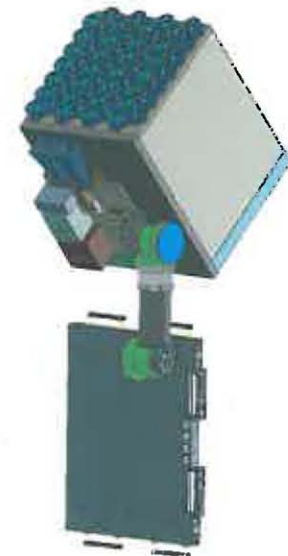
# SEXTANT Payload



Stowed



Deploying



Pointing

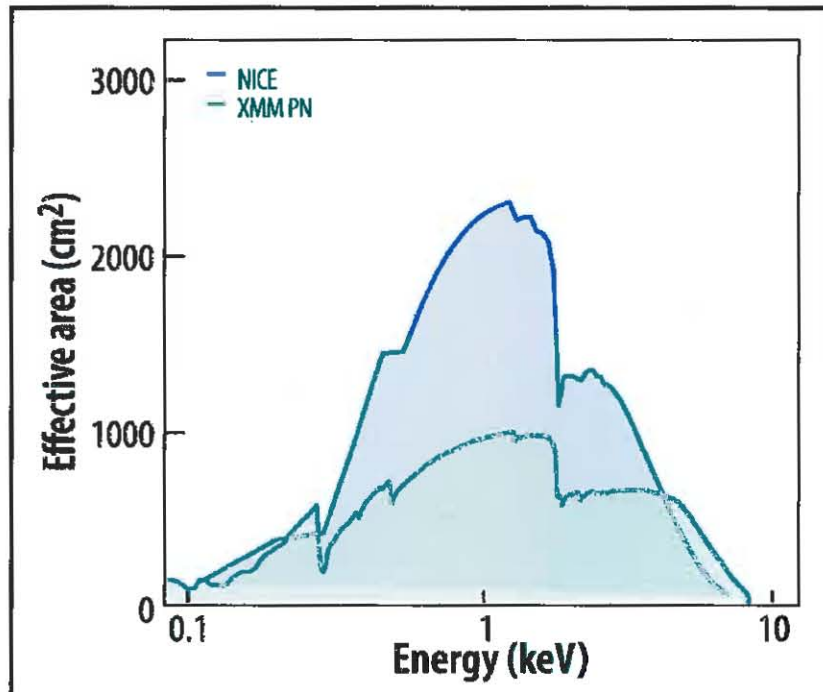
- 56 co-aligned X-ray concentrators with matching Silicon Detectors
- < 200 nsec absolute time resolution
- > 2000 cm<sup>2</sup> Effective Area
- Moderate (CCD-like) energy resolution



# Deployment and pointing scheme



# SEXTANT OPTICS



- Derivatives of GSFC foil optics- continued legacy of Peter Serlemitsos
- Single bounce concentrators
- Full shells with deviation from cone
- Order of magnitude improvement on area/ mass ratio
- XACT sounding rocket will use similar optics



1<sup>st</sup> partial assembly of XACT optics



1<sup>st</sup> optical image from XACT optics FWHM  $\sim$  < 1 arcmin

# The X-ray Detectors

- Silicon Drift Detectors
- Commercial with Custom Designed Electronics
- Excellent Timing capability and Energy Resolution
  - But there is still a timing jitter term
- Summer 2010 USNA Midshipman Spencer Ewing Project



## Background

- Incident X-rays enter silicon; energy frees electron from silicon atoms.
- Concentric drift rings are charged at increasingly negative voltages outside of the center signal anode.
- Drift rings guide freed electrons to move toward central sensing signal anode.
- Signal anode is read out by a preamplifier that converts the charge signal to a voltage signal.
- The further the initial X-ray interaction is from the sensing anode, the longer the drift time.

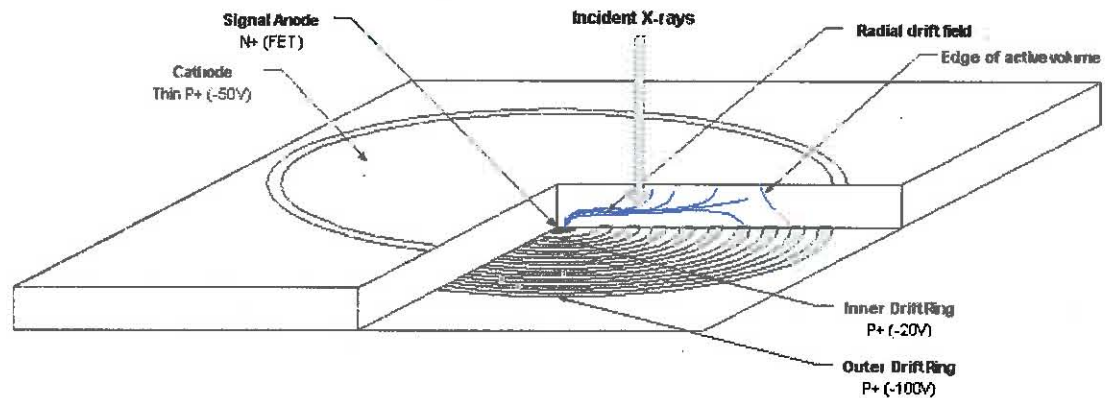


Figure 1: Illustration of SDD from AMPTEK

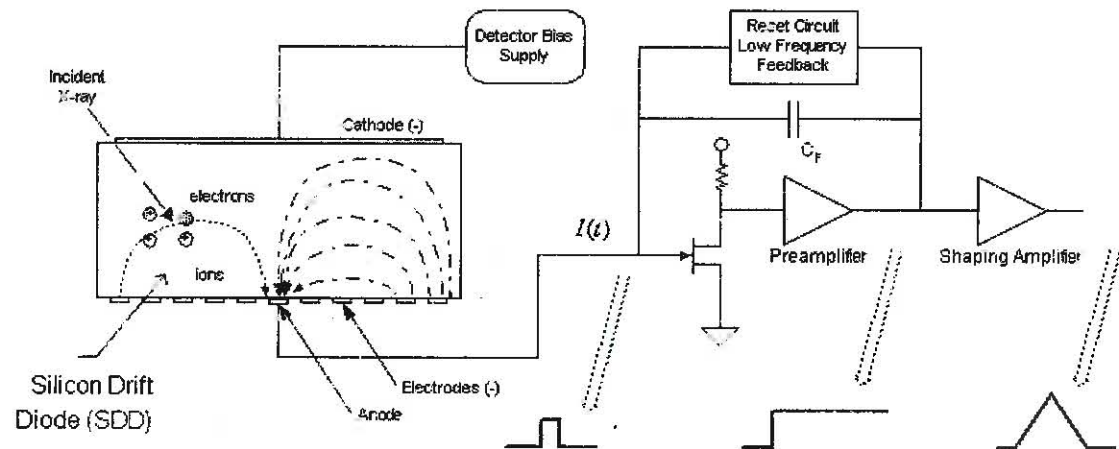
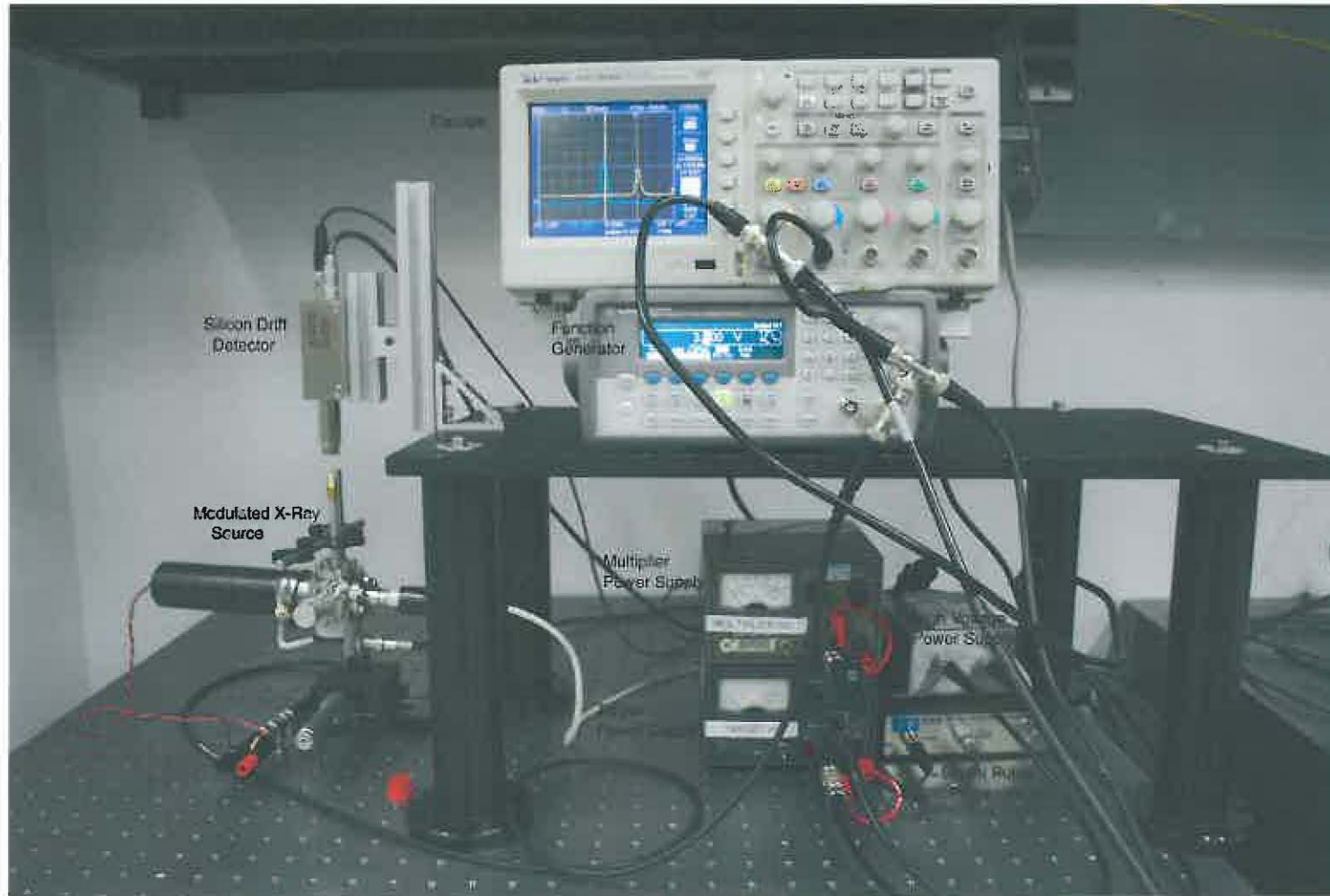


Figure 2: Diagram of how the SDD works from AMPTEK

## Experiment Setup

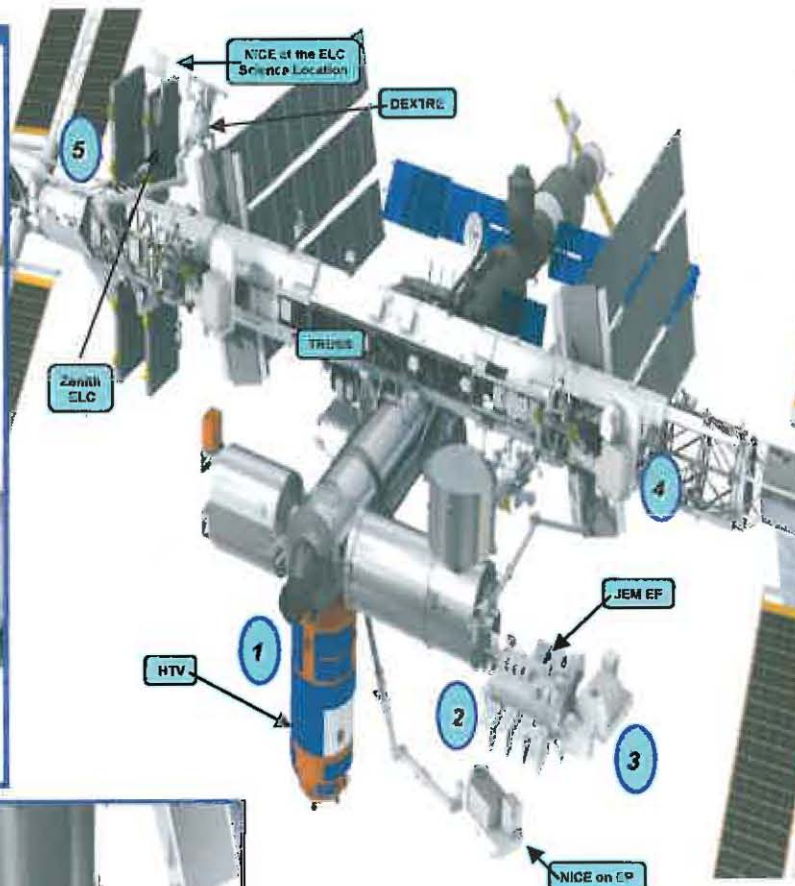


Function Generator (FG) the modulated X-ray source, producing a 60nsec wide pulse done at a 500 kHz rate.  
Additional power supplies needed to power the MXS.  
Data Acquisition compiled by Digital Pulse Processor, relayed to Oscope.  
Scope averaged 100 triggers of data to reduce errors.

# Operations Concept

- Getting from the Earth to ISS
- Robotic Installation
- Getting the science done, once we are there
  - USNA Midshipman Putbrese is working with Prof Tae Lim and GSFC engineers on a planning tool.





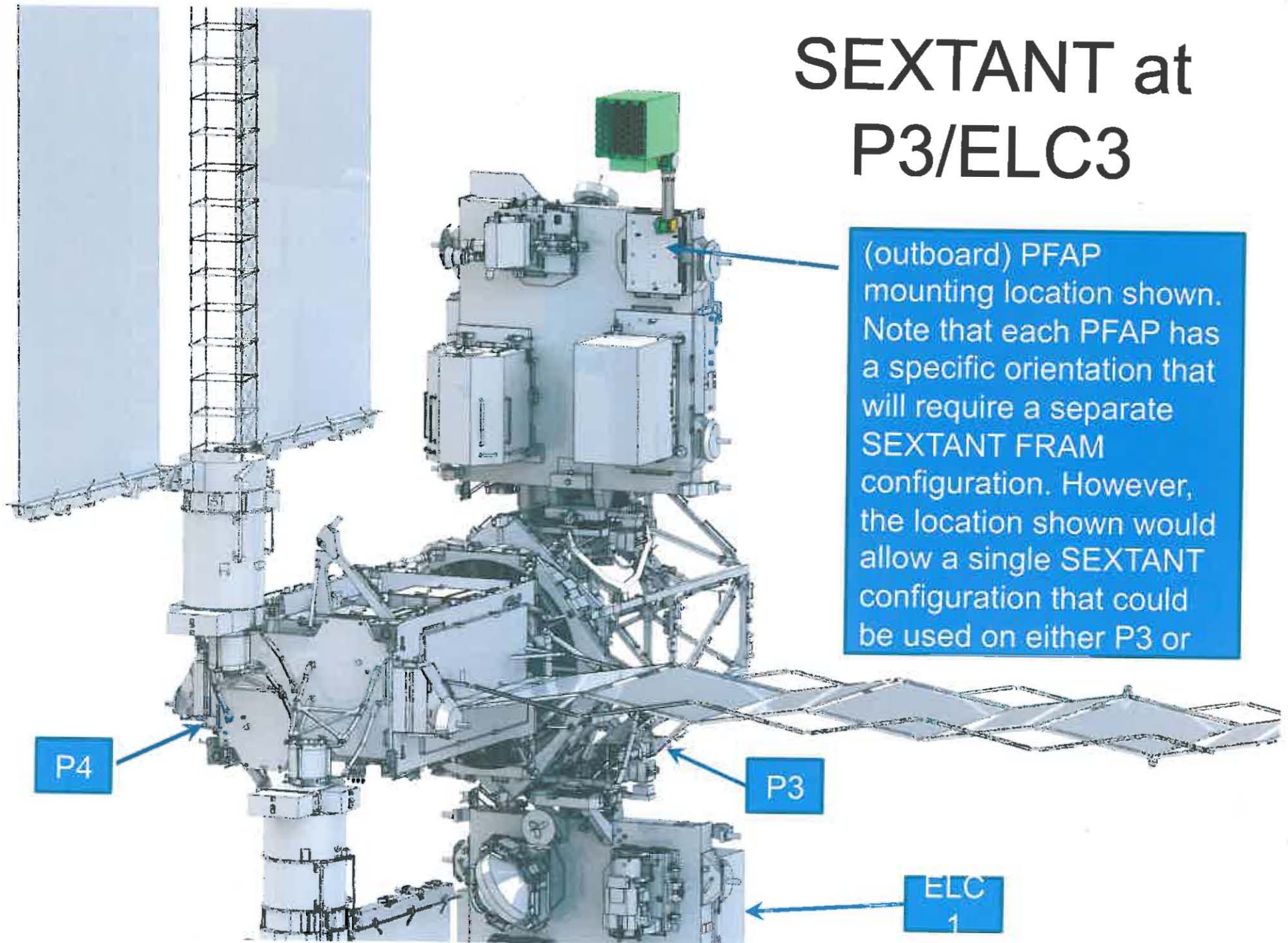
The NICE payload arrives at ISS on the External Pallet within the exposed logistics module of the HTV. After the HTV is berthed to Node 2, the SSRMS removes the External pallet (EP) from the HTV (1). Once clear of the HTV, the SSRMS positions the EP so it can hand it off to the JRMS (2). Once the JRMS grapples the EP, it moves the EP to a temporary storage attach point (3) on the JEM Exposed Facility (JEM-EF) where it remains until ready for installation on the zenith S3 Express Logistics Carrier (ELC).

The JRMS removes the EP from the temporary attach point and moves it to the Latching End Effector (LEE) on the Mobile Base System (MBS) (4). Once attached, the MBS translates the EP, as well as the SSRMS and DEXTRE starboard from the P1/P3 Truss to the S3 Truss. The DEXTRE robot is installed onto the end of the SSRMS, DEXTRE removes NICE from the EP and installs it onto the zenith ELC (5).

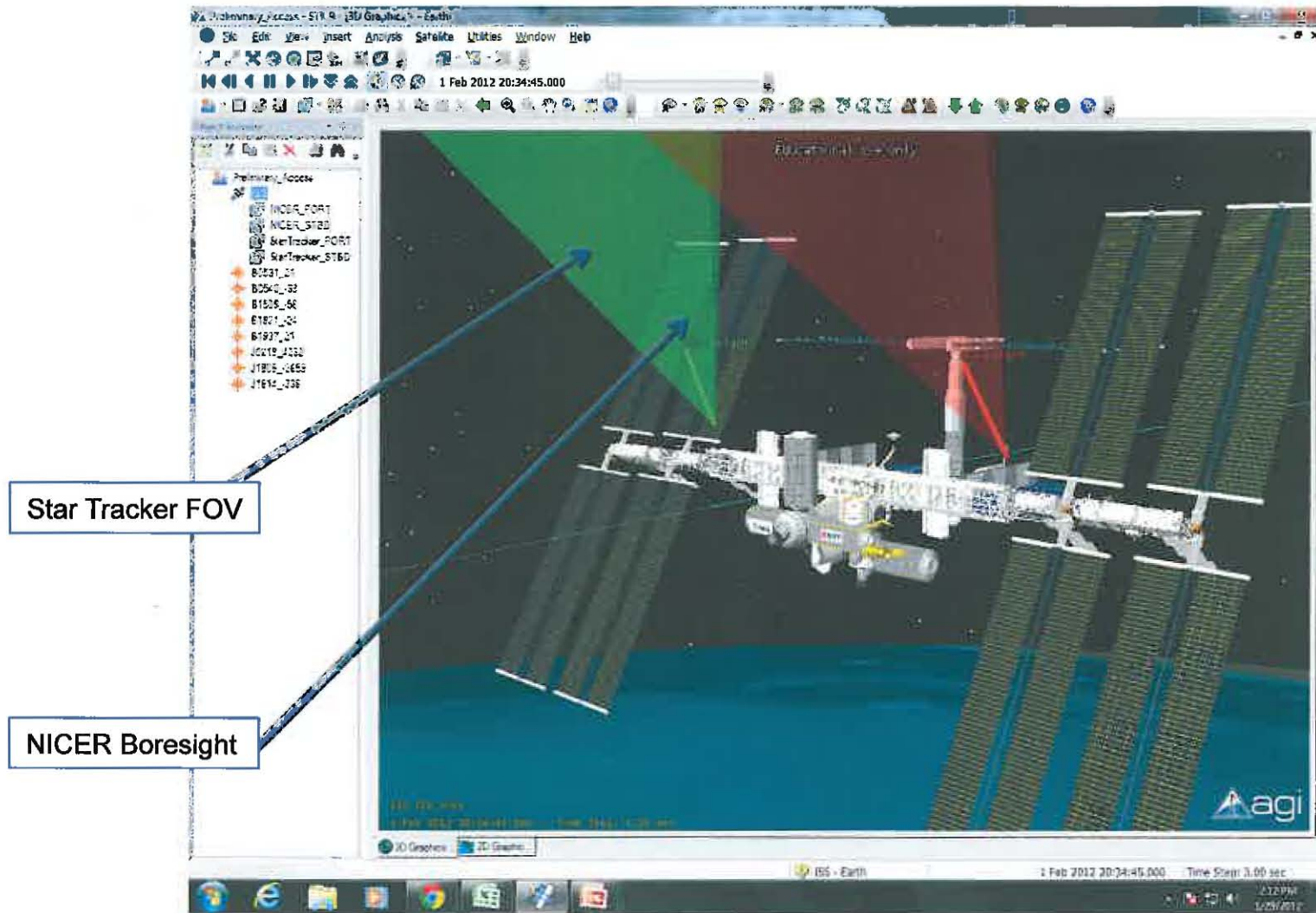




# SEXTANT at P3/ELC3



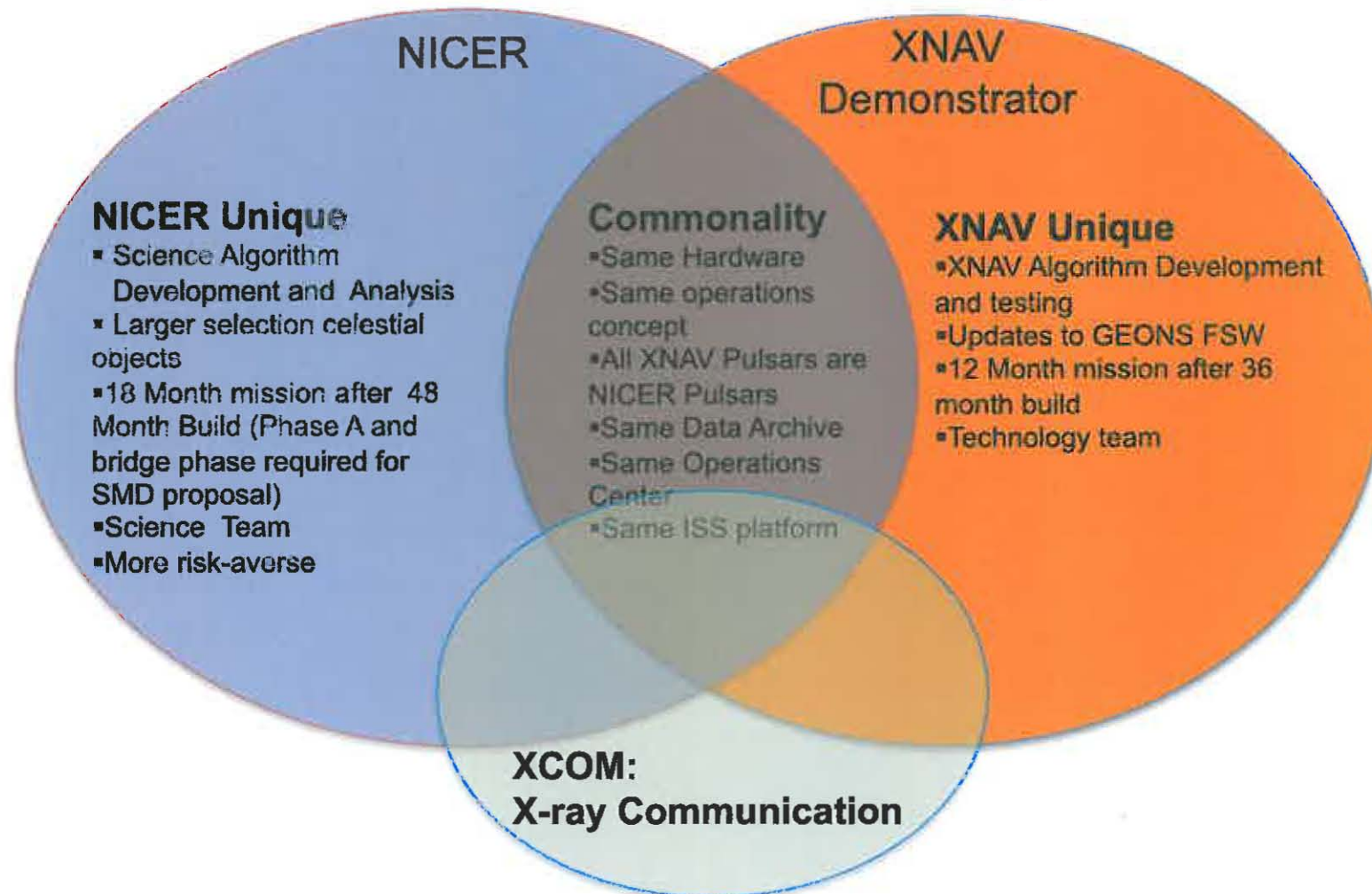
# 3-D Model – ISS



# Science and backup



# SEXTANT: Station Explorer for X-ray Timing and Navigation Technology



**SEXTANT = NICER + XNAV + XCOM**



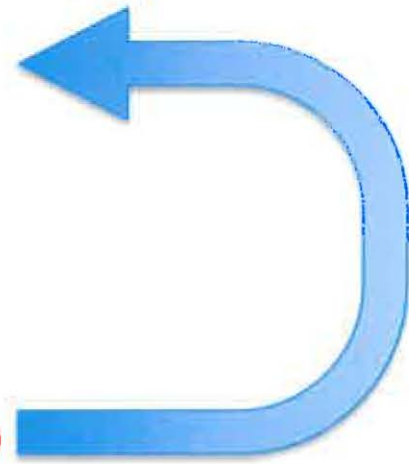
## Ongoing Millisecond Pulsar Discoveries Promise Many New NICER Targets!



# What is the best way to detect the pulses of a Pulsar?

- Radio
  - 10m diameter dishes or greater
  - RF propagation terms
- Optical
  - Very Faint-> requires large telescope
- X-ray
  - ~ few hundred square cm of area good enough
- Gamma Ray
  - massive detectors required

X-ray Navigation (XNAV)



2. SSRMS berths  
SPDM (with  
SEXTANT on EOTP)  
on US Lab PDGF.  
SSRMS  
reconfigures onto  
MBS PDGF

4a. MBS (with SSRMS and  
SPDM) translates to S3  
worksite. SPDM removes  
SEXTANT from EOTP and  
installs onto ELC2

1. Dragon berthed at Node 2  
Nadir. SSRMS/SPDM  
removal from trunk. SPDM  
stows SEXTANT on EOTP

3. SSRMS grapples  
SPDM (with  
SEXTANT on  
EOTP)

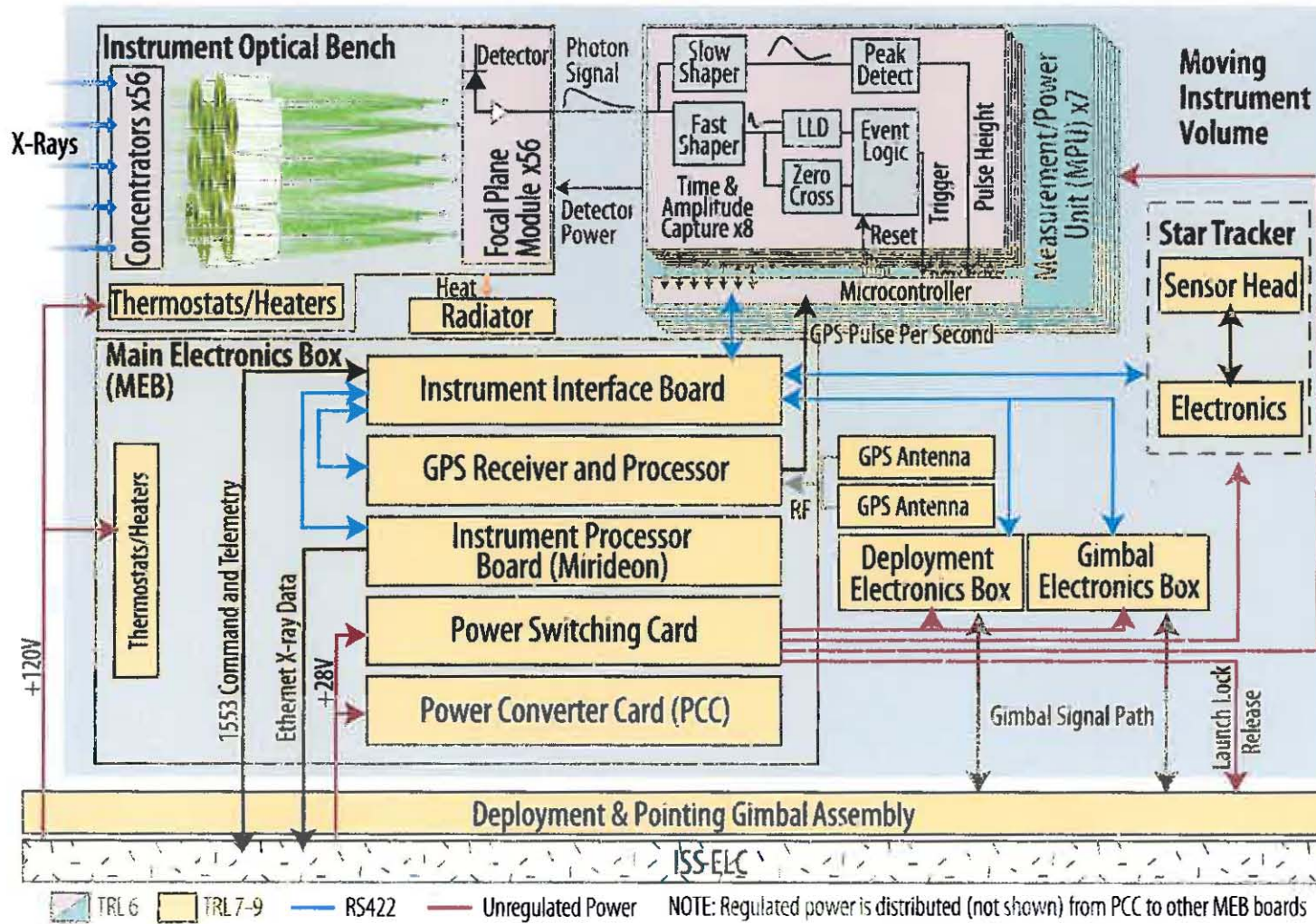
4b. MBS (with SSRMS and  
SPDM) translates to P3  
worksite. SPDM removes  
SEXTANT from EOTP and  
installs onto ELC3

# SEXTANT Dragon Deployment

Preliminary!!



# Instrument Block Diagram



Instrument Performance		
Bandpass & Effective Area	0.2-12 keV 2300 cm <sup>2</sup> @ 1.5 keV, 600 cm <sup>2</sup> @ 6 keV	
Energy Resolution	3% @ 6 keV, 10% @ 1 keV	
Timing Resolution	Detector	150 ns
	GPS to UTC	50 ns
	GPS pos'n	30 ns
	Total RSS	161 ns
Spatial Resolution	3 arcmin	
Pointing Control Budget (arcsec)	Control	50
	Boresight	15
	ISS Jitter	11
	Thermal	11
	Tracker	2
	Total RSS	76
Sensitivity (unpulsed), 0.4-10 keV	2.2 x 10 <sup>-14</sup> ergs/s/cm <sup>2</sup> , 5 $\sigma$ in 10 ksec	